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PHYSICAL CHEMISTRY.—*The compressibility of rubber.*[1] L. H. ADAMS and R. E. GIBSON, Geophysical Laboratory, Carnegie Institution of Washington.

Although many of the elastic properties of rubber have been investigated with very interesting results, no measurements have been made, so far as we know, of its cubic compressibility at high pressures. Those measurements which have been made at low pressures yield results varying from $93 \times 10^{-6}$ obtained by CLAPEYRON[2] to an estimate of the order of the compressibility of bronze (about $1 \times 10^{-6}$) given by AMAGAT.[3] As the compressibility of rubber enters as a minor correction into most compressibility measurements at high pressures, it is very desirable to have a reliable estimate of its value. In this communication we propose to give the results of experimental determinations of the compressibility at 25° of three samples of rubber which were furnished to us by Messrs. H. L. CURTIS and A. H. SCOTT of the U. S. Bureau of Standards.

The samples are described as follows:

*Sample A.* Hard rubber from panel made by the Goodrich Company. It is a rubber-sulfur compound containing no inorganic fillers. The total sulfur amounts to 27.4 per cent of which 0.21 per cent is free sulfur. The density is 1.149 at 27°C.

*Sample B.* A rubber-sulfur compound containing 90 per cent smoked rubber and 10 per cent sulfur and vulcanized 105 minutes at 300°F. Density = 0.990 at 25°.

*Sample C* consists of pale crepe rubber 90.75 per cent, zinc oxide 5 per cent, sulfur 4 per cent, tetramethylthiuram disulfide 0.25 per cent. It was vulcanized for 30 minutes at 260°F. Density = 0.990 at 27°.

[1] Received March 26, 1930.
[2] Compt. rend. **46**: *208*. 1858.
[3] See LUNDAL, Ann. Physik **66**: *741*. 1898.

Samples B and C were called soft rubber.

The samples of rubber were cut into discs and built up to form cylinders approximately 20 cc. in volume. On such specimens were the compressibility measurements made. The technique employed for such measurements in this Laboratory has already been described in detail,[4] and may be summarized as follows. The rubber was placed in a heavy-walled steel cylinder and completely surrounded by a suitable liquid. The volume of the liquid was then diminished by forcing a special piston into the cylinder and the pressure so generated read to one bar[5] by an electrical resistance gauge. The travel of the piston which was a function of the decrease in volume was measured by a dial micrometer gauge. The apparatus was calibrated at frequent intervals with a substance whose compressibility is accurately known—viz. cold rolled steel.[6] In this way adequate corrections for the compressibility of the pressure-transmitting liquid, for the stretching of the bomb, and for the distortion of the packings were made.

All readings were made by adhering rigorously to a definite procedure. The pressure was first raised to 12,400 bars and then lowered to about 50 b. below 12,000. A pause was made for temperature readjustment and then the pressure slowly raised to as near 12,000 b. as possible. After the piston displacement had been read, the pressure was lowered to 10,950 b. and after a pause brought back to 11,000 b. A reading was made and the process repeated for successively lower pressures at intervals of 1000 b. Unless a definite procedure is followed in all the experiments, serious errors from hysteresis in the bomb and packings are apt to be introduced. Especially necessary is it that the runs with the specimen under investigation be made exactly like those with the standard steel.

*Results.* The experimental observations which consist of two series of pressure and piston displacements, one for the rubber and one for the steel, are converted by a calculation which has already been described[7] to a single table of pressures (Table 1) and the corresponding values

[4] ADAMS, WILLIAMSON and JOHNSTON. Journ. Am. Chem. Soc. **41**: *12*. 1919; ADAMS and WILLIAMSON. Journ. Franklin Inst. **195**: *475*. 1923.

[5] 1 bar (b.) = $10^6$ dynes/cm.$^2$ = 0.987 atmosphere. According to the International Critical Tables this is the only internationally accepted use of the word "bar," although it has been used to mean 1 dyne per sq. cm. We advocate the more general use of the word bar instead of megabarye, which we have hitherto employed, to indicate $10^6$ dynes/cm.$^2$, particularly because of the convenience of the term "kilobar" which denotes one thousand bars (approximately 1000 atm.) and is the logical high-pressure unit.

[6] P. W. BRIDGMAN. Proc. Am. Acad. Arts Sci. **58**: *166*. 1923.

[7] ADAMS and WILLIAMSON. Journ. Franklin Inst. **195**: *475*. 1923.
ADAMS and GIBSON. Proc. Nat. Acad. Sci. **12**: *275*. 1926.

of $-\frac{\Delta V}{V_0}$, the fractional change in volume of the rubber, $-\frac{\Delta V}{V_0}$ being zero at 2000 b. Column A refers to the hard rubber, Column B to the rubber containing 10 per cent sulfur, and Column C to rubber with 4 per cent sulfur.

In order to smooth the results and to determine the volume change and compressibility at any pressure it is our custom to express $-\frac{\Delta V}{V_0}$ as a function of pressure—usually as a function of $(p - 2000)$. With most solids this is comparatively simple, as a linear or quadratic equation fitted to the data by the method of least squares represents the observations very exactly.

TABLE 1.—EXPERIMENTAL RESULTS

$-\frac{\Delta V}{V_0} \times 10^3$ (Obs.)

| Pressure in bars ($p$) | A | B | C |
|---|---|---|---|
| 12000 | 10.085 | 10.463 | 11.222 |
| 11000 | 9.442 | 9.864 | 10.608 |
| 10000 | 8.733 | 9.217 | 9.922 |
| 9000 | 7.994 | 8.528 | 9.200 |
| 8000 | 7.177 | 7.780 | 8.410 |
| 7000 | 6.267 | 6.967 | 7.535 |
| 6000 | 5.255 | 6.010 | 6.498 |
| 5000 | 4.129 | 4.925 | 5.233 |
| 4000 | 2.903 | 3.566 | 3.779 |
| 3000 | 1.514 | 1.940 | 2.056 |
| 2000 | 0.000 | 0.000 | 0.000 |
| 1000 | −1.692 | −2.442 | −2.682 |

The volume changes produced when rubber is compressed hydrostatically can not be represented by a quadratic equation. Indeed, the compressibility of rubber is more like that of a liquid than of a solid. At low pressures the compressibility is very high but it falls off rapidly at the higher pressures, the behavior being closely akin to that of a liquid. Up to the present no satisfactory equation has been devised for expressing $-\frac{\Delta V}{V_0}$ for liquids as a function of the pressure over any considerable range of pressures.

Among others,[8] three equations involving four constants each were tried: (a) a cubic, (b) an hyperbola, (c) an exponential function. These three equations will now be discussed.

[8] Several other types of equations, based on the published equations of state, were tried but the results were not as good as those for the three equations which are discussed here.

(a) *Cubic Equations.* The first equation tried was of the form:

$$y = a + bx + cx^2 + dx^3 \qquad (1)$$

where, as throughout this paper, $y = -\frac{\Delta V}{V_0} \times 10^5$ and $x = \frac{p-2000}{1000}$. It was fitted to the three sets of results by the method of least squares. The results are summarized in Table 2 where the figures in the column labeled "obs.-calc." refer to the difference between the observed value of $y$ (Table 1) and those calculated by the following equations:

$$y = -4 + 1603.4x - 80.67x^2 + 2.121x^3 \qquad (1A)$$

$$y = 18 + 2075.0x - 169.52x^2 + 6.677x^3 \qquad (1B)$$

$$y = 8 + 2199.3x - 170.15x^2 + 6.2535x^3 \qquad (1C)$$

TABLE 2.—REPRESENTATION OF RESULTS BY MEANS OF CUBIC EQUATIONS

| $p$ | Sample A | | Sample B | | Sample C | |
|---|---|---|---|---|---|---|
| | $-\frac{\Delta V}{V_0} \times 10^5$ (Calc.) | Obs.-Calc. $\times 10^4$ | $-\frac{\Delta V}{V_0} \times 10^5$ (Calc.) | Obs.-Calc. $\times 10^4$ | $-\frac{\Delta V}{V_0} \times 10^5$ (Calc.) | Obs.-Calc. $\times 10^4$ |
| 12000 | 10.084 | 0.1 | 10.493 | −3.0 | 11.240 | −1.8 |
| 11000 | 9.439 | 0.3 | 9.830 | 3.4 | 10.579 | 2.9 |
| 10000 | 8.746 | −1.3 | 9.188 | 2.9 | 9.914 | 0.8 |
| 9000 | 7.995 | −0.1 | 8.527 | 0.1 | 9.211 | −1.1 |
| 8000 | 7.170 | 0.7 | 7.807 | −2.7 | 8.430 | −2.0 |
| 7000 | 6.261 | 0.6 | 6.990 | −2.3 | 7.532 | 0.3 |
| 6000 | 5.255 | 0.0 | 6.033 | −2.3 | 6.483 | 1.5 |
| 5000 | 4.137 | −0.8 | 4.897 | 2.8 | 5.244 | −1.1 |
| 4000 | 2.897 | 0.6 | 3.543 | 2.3 | 3.776 | 0.3 |
| 3000 | 1.520 | −0.6 | 1.930 | 1.0 | 2.043 | 1.3 |
| 2000 | −0.004 | 0.4 | 0.018 | −1.8 | 0.008 | −0.8 |
| 1000 | −1.690 | 0.2 | −2.233 | −20.9 | −2.367 | −31.5 |

Equation 1A represents the observations on hard rubber very satisfactorily. The deviations are so small that it was felt that no further computations were necessary for the hard rubber results.

It appears, however, that a cubic equation does not give a good representation of the volume changes under pressure for the two samples of soft rubber, the worst feature being the apparent failure of the equations at the top and bottom of the table. The large deviation at 1000 b. illustrates this clearly and if $\frac{dy}{dx}$ obtained by differentiating equation B is plotted against $x$ it will be seen to pass through a minimum at 10,000 b., a circumstance which is most improbable.

We might conclude by saying that a cubic represents the fractional change in volume of hard rubber as a function of pressure very well, but that a cubic equation may only be used as a short interpolation equation with the two soft rubbers.

(b) *Hyperbolic Equations.* An equation of the type

$$y\ (x + \text{const.}) = a + bx + cx^2 \qquad (2)$$

was applied to the data for samples B and C. The results, given in Table 3 and calculated with the following equations are disappointing:

$$y\ (x + 8.0) = 293 + 17290.4x + 145.83x^2 \qquad (2B)$$
$$y\ (x + 8.0) = -206 + 18883.8x + 130.61x^2 \qquad (2C)$$

(c) *Exponential Equations.* The large decrease in volume at lower pressures which diminishes at high pressures suggests an equation of the type

$$y = A + Bx + C\ (1 - e^{-\ }) \qquad (3)$$

As $x$ gets large the last term of the equation approaches zero and we are left with the equation

$$y = A + Bx.$$

TABLE 3.—REPRESENTATION OF RESULTS FOR TWO TYPES OF SOFT RUBBER BY A HYPERBOLA

| $p$ | Sample B | | Sample C | |
|---|---|---|---|---|
| | $-\frac{\Delta V}{V_0} \times 10^3$ (Calc.) | Obs.-Calc. $\times 10^4$ | $-\frac{\Delta V}{V_0} \times 10^3$ (Calc.) | Obs.-Calc. $\times 10^4$ |
| 12000 | 10.432 | 3.1 | 11.205 | 1.7 |
| 11000 | 9.866 | −0.2 | 10.608 | 0.0 |
| 10000 | 9.247 | −3.0 | 9.951 | −2.9 |
| 9000 | 8.565 | −3.7 | 9.225 | −2.5 |
| 8000 | 7.806 | −2.6 | 8.414 | −0.4 |
| 7000 | 6.953 | 1.4 | 7.498 | 3.7 |
| 6000 | 5.982 | 2.8 | 6.452 | 4.6 |
| 5000 | 4.861 | 6.4 | 5.238 | −0.5 |
| 4000 | 3.546 | 2.0 | 3.808 | −2.9 |
| 3000 | 1.970 | −3.0 | 2.090 | −3.4 |
| 2000 | 0.037 | −3.7 | −0.026 | 2.6 |
| 1000 | −2.407 | −3.5 | −2.708 | 2.6 |

The value of $D$ may be estimated graphically as follows. It will be seen that the logarithm of the second derivative of $y$ with respect to $x$ is

$$\log \frac{d^2y}{dx^2} = \log\ (-CD^2) - Dx$$

or that the logarithm of $\frac{d^2y}{dx^2}$ is a linear function of $x$ whose slope is $-D$. From a table of $x$ as argument and $y$ as entry we determined the second differences which corresponded to the second derivative. The logarithms of the second differences were plotted against $x$ and the plot was approximately a straight line whose slope gave us an estimate of $D$. Using this value of $D$ we were able to get tentative values of $A$, $B$ and

$C$ ($A'$, $B'$ and $C'$) by substituting three of the observed values of $x$ and $y$ in equation 3, and hence calculating values of $y$ at all pressures. The differences between $y$ obs. and $y$ calc. ($\Delta y$) were plotted and a smooth deviation curve drawn. This curve was represented by the equation:

$$\Delta y = a + bx + c\,(1 - e^{-Dx})$$

where $D$ is the same as in the above calculation.

It may easily be shown that by adding $a$, $b$ and $c$ to $A'$, $B'$ and $C'$ an equation is obtained which gives the fairest representation of the data possible with an equation of this type.

The final equations were as follows:

$$y = -9 + 482.2x + 5967\,(1 - e^{-0.29x}) \qquad (3B)$$

$$y = -45 + 484.85x + 6890\,(1 - e^{-0.27x}) \qquad (3C)$$

Calculations made with equations 3B and 3C are tabulated in Table 4.

TABLE 4.—REPRESENTATION OF RESULTS FOR TWO TYPES OF SOFT RUBBER BY AN EXPONENTIAL EQUATION

| $p$ | Sample B | | Sample C | |
|---|---|---|---|---|
| | $-\frac{\Delta V}{V_0} \times 10^3$ (Calc.) | Obs.-Calc. $\times 10^4$ | $-\frac{\Delta V}{V_0} \times 10^3$ (Calc.) | Obs.-Calc. $\times 10^4$ |
| 12000 | 10.452 | 1.1 | 11.231 | −0.9 |
| 11000 | 9.859 | 0.5 | 10.602 | 0.6 |
| 10000 | 9.230 | −1.3 | 9.929 | −0.7 |
| 9000 | 8.549 | −2.1 | 9.198 | 0.2 |
| 8000 | 7.804 | −2.4 | 8.390 | 2.0 |
| 7000 | 6.969 | −0.2 | 7.484 | 5.1 |
| 6000 | 6.016 | −0.6 | 6.445 | 5.3 |
| 5000 | 4.905 | 2.0 | 5.235 | −0.2 |
| 4000 | 3.581 | −1.5 | 3.800 | −2.1 |
| 3000 | 1.975 | −3.5 | 2.070 | −1.4 |
| 2000 | −0.009 | 0.9 | −0.045 | 4.5 |
| 1000 | −2.498 | 5.6 | −2.666 | −1.6 |

Here, again, the magnitude of the residuals is greater than our estimated experimental error and undoubtedly equation 3 does not represent the soft rubber results as well as the cubic equation represents those for the hard rubber. We would emphasize that the trend in the deviations of both the exponential and the hyperbolic equations, which is obvious from a study of Tables 3 and 4, should be taken as a warning that extrapolation with these equations is dangerous and that at best they are empirical interpolation formulae. On the other hand, we

found that the course of $\frac{dy}{dx}$ as calculated from equations 3B and 3C agreed very well with the course of the first differences of the observations from 1000 to 11,000 b., and, moreover, the value of $-\frac{\Delta V}{V_0}$ between 1 and 2000 b. calculated from the equations 3B and 3C and corrected by the deviation curves agreed very well with our most reliable estimate obtained from a cubic passed through the points at 1000, 2000 and 3000 b.

Of all the equations fitted to the soft rubber results we prefer the exponential one. It represents the results as closely as does the hyperbola and is easier to handle.

For the hard rubber, smoothed reliable values of $-\frac{\Delta V}{V_0}$ reckoned from 2000 b. may be obtained at any pressure by application of equation 1A, but as, up to the present, we have found no equation which represents the data to the order of the experimental error and even the course of the deviation curves is doubtful, we have no way of obtaining smoothed and accurate values of $-\frac{\Delta V}{V_0}$ for the samples of soft rubber. If it is desired to calculate this at intermediate pressures, equations 3B or 3C may be used, which will give approximate values of $-\frac{\Delta V}{V_0}$ when used alone, and accurate ones when combined with the deviation curves.

In Fig. 1 we have plotted values of the relative decrease in volume, $-\frac{\Delta V}{V_0}$, reckoned from atmospheric pressure, against the pressure, for the three samples of rubber examined. These curves serve to illustrate the volume changes undergone by each type of rubber under hydrostatic pressure and, moreover, indicate the consistency of our determinations. The points plotted in Fig. 1 are the observations taken from Table 1 to which has been added the average value of the volume change from 0 to 2000 b. estimated by all the equations and their deviation curves.

For sample A, the hard rubber, the values of $-\frac{\Delta V}{V_0}$ reckoned from atmospheric pressure and corresponding values of the compressibility, $\beta$, are given by the equations

$$-\frac{\Delta V}{V_0} = 19.515 \times 10^{-6}\, p - 9.34 \times 10^{-10} p^2 + 2.121 \times 10^{-14} p^3$$

$$\beta = 19.515 \times 10^{-6} - 18.68 \times 10^{-10} p + 6.36 \times 10^{-14} p^2$$

where the pressure $p$ is expressed in bars. These equations may be used directly to calculate the change in volume or the compressibility at any pressure.

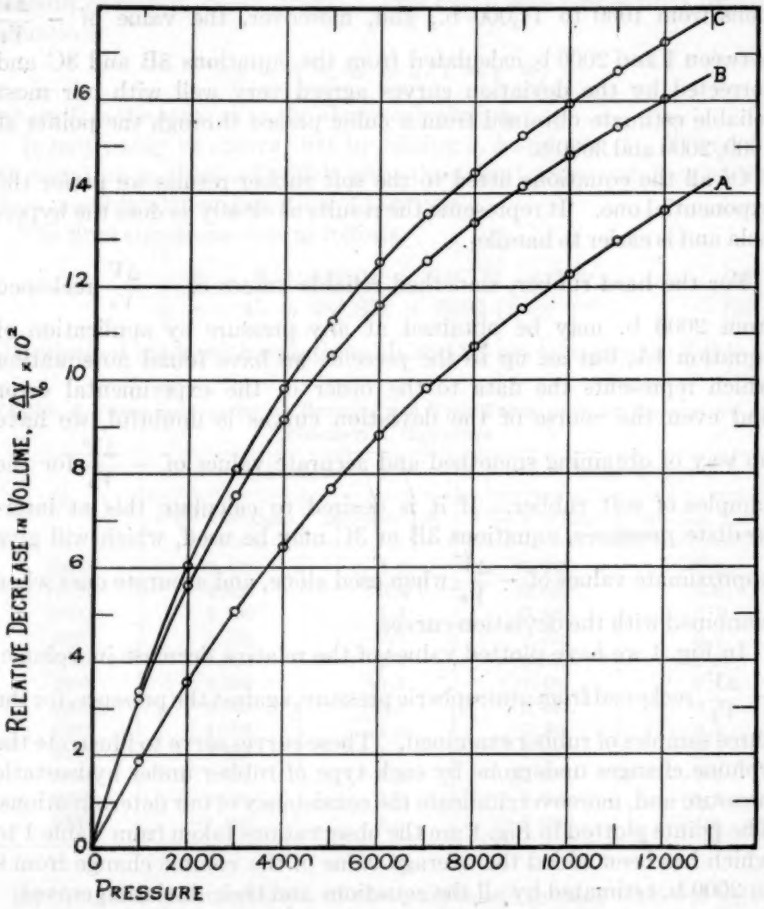



Fig. 1. Relation between percentage change in volume and pressure for three samples of rubber.

Equations 4B and 4C give very close approximations to the compressibilities of samples B and C respectively.

$$\beta_B = \frac{dy}{dx} = 482.2 + 1730\, e^{-0.29x} \qquad (4B)$$

$$\beta = \frac{dy}{dx} = 484.5 + 1860\, e^{-0.27x} \qquad (4C)$$

Over the range from 2000 to 11,000 b. they are reliable, but if more accurate values are desired deviation curves may be constructed by plotting the figures in Columns 3 and 5 of Table 4 against the pressure $x$, determining the slopes at the required pressures and adding them to the values of $\beta$ calculated by 4B and 4C. As $x$ is equal to $\frac{p-2000}{1000}$, where $p$ is in b., we may convert equations 4B and 4C to a form in which the pressure is given in b.

$$\beta_B = 4.822 \times 10^{-6} + 30.90 \times 10^{-6} e^{-0.00029p} \qquad (4'B)$$

$$\beta_C = 4.845 \times 10^{-6} + 31.92 \times 10^{-6} e^{-0.00027p} \qquad (4'C)$$

*Discussion of Results.* The main results about the compressibility of rubber containing various amounts of sulfur are recorded graphically in Fig. 2, where they are compared with the compressibilities of a liquid, amyl alcohol;[9] of a highly compressible solid, potassium;[10] of sodium chloride,[11] and of steel.[6] As might be expected, the compressibility-pressure curves for the two types of soft rubber are closely akin to the curve for amyl alcohol, the liquid, and show little in common with the curve for NaCl or even for potassium. It is true that the compressibility of potassium is the same as that of soft rubber at zero pressure, but the compressibility-pressure curves are radically different, resulting in the compressibility of rubber at 12,000 b. being approximately one-third of that of potassium. The compressibility-pressure curve of hard rubber (A) seems to be similar to that of potassium, being more like the curve of a compressible solid than that of a liquid.

Unavoidable differences in the volume of rubber washers used in the piston of the high pressure apparatus result in the substitution of a small volume of pressure-transmitting liquid for rubber, or vice versa. We have just seen that the compressibility of rubber is not much less than that of organic liquids and so the magnitude of the correction introduced by the substitution of a few cubic millimeters of butyl ether for rubber is practically negligible.

It is interesting to note that while soft rubber, sample B, is almost twice as compressible as hard rubber at atmospheric pressure, it is less compressible than the hard rubber at pressures above 5000 b. Undoubtedly the large amount of sulfur, 27 per cent in the hard rubber, has a decided influence on its compressibility, lowering it at

[9] P. W. BRIDGMAN. Proc. Am. Acad. Arts Sci. **49**: *53*. 1913.
[10] P. W. BRIDGMAN. Proc. Am. Acad. Arts Sci. **58**: *204*. 1923.
[11] ADAMS, WILLIAMSON and JOHNSTON. Op. cit.

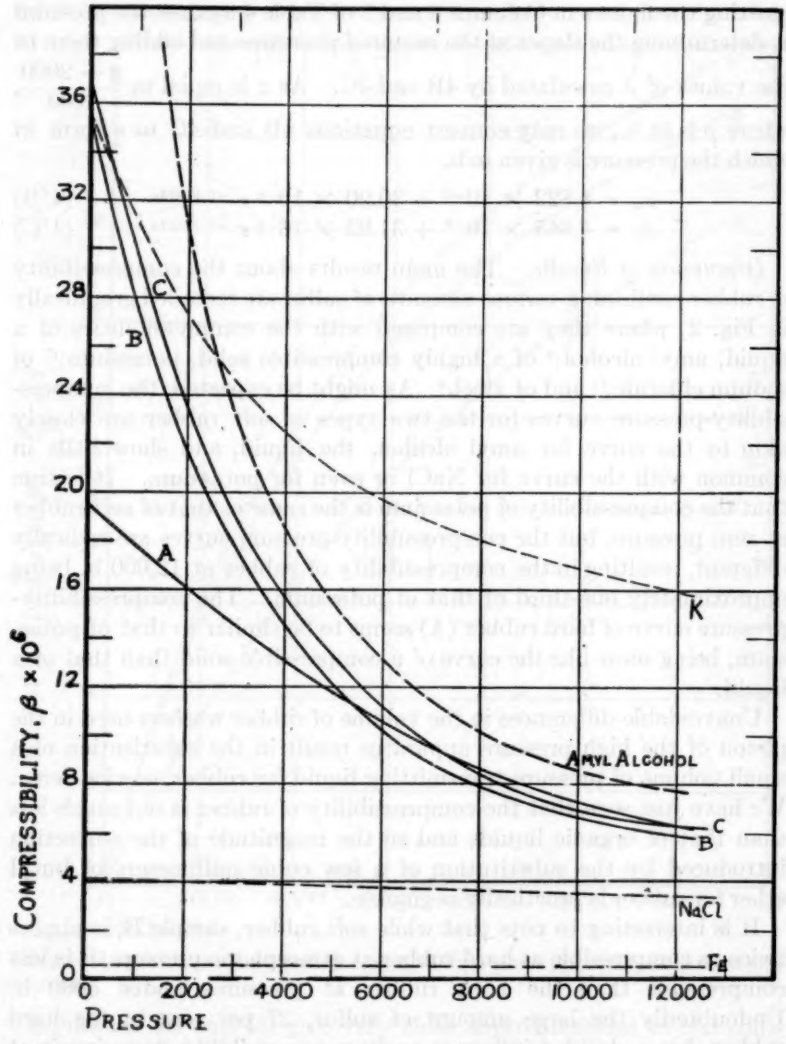



Fig. 2. Change of compressibility of rubber with pressure as compared with that of liquids and solids.

the lower pressures and keeping the value large at the high pressures. In fact, curve A might well be regarded as composed of two curves, the first similar to curve B and the second a straight line cutting the y-axis at 13.1 and of slightly negative slope. The compressibility of sulfur is 13.1 at 1 mb.[12] and it probably exhibits the normal diminution with pressure. Fig. 1 shows that if the volume of a piece of hard rubber is 100 cc. at atmospheric pressure, its volume at 12,000 b. is only 85.4 cc. and that under a similar pressure change the volume of a piece of soft rubber containing 10 per cent of sulfur would decrease from 100 cc. to 82.8 cc. These figures emphasize in a striking way the very large changes in volume which are produced when a solid like rubber is subjected to large hydrostatic pressure.

ZOOLOGY.—*A new pocket mouse from southern Lower California.*[1]

E. W. NELSON and E. A. GOLDMAN, Biological Survey.

The occurrence of the large pocket mouse, *Perognathus baileyi*, in Lower California was first made known by Elliot (Field Columb. Mus., Publ. 74, Zool. Ser., vol. 3, April, 1903, p. 167) who described *P. b. rudinoris* a dark form from San Quintin. *Perognathus knekus* Elliot, from Rosarito, San Pedro Martir Mountains, which was published at the same time (l.c. p. 169) was based, as comparison shows, on an unusually large specimen of *rudinoris*. A pallid subspecies was described from San Felipe, northeastern Lower California by Nelson and Goldman (Proc. Biol. Soc. Washington, vol. 42, March 25, 1929, p. 104). Specimens from localities in the central and southern part of the peninsula had been referred to *rudinoris*, but more critical comparisons indicate the desirability of segregating the subspecies described as follows:

**Perognathus baileyi extimus** subsp. nov.

Southern Peninsular Pocket Mouse

*Type.*—From Tres Pachitas, 36 miles south of La Paz, Lower California, Mexico (altitude 700 feet). No. 146672, ♀ adult, U. S. National Museum (Biological Survey collection), collected by Nelson and Goldman, December 25, 1905. Original number 18785.

*Geographic distribution.*—Low elevations in Lower California from the type locality south of La Paz north to near Latitude 30°, intergrading to the northward with *Perognathus baileyi rudinoris* and *P. b. hueyi*.

[12] T. W. RICHARDS. Journ. Am. Chem. Soc. **37**: *1646*. 1915.

[1] Received April 28, 1930.

*General characters.*—A light, buffy subspecies with nearly pure white forearms and grayish ears. Similar to *P. b. rudinoris*, but lighter, more buffy, the upper parts in general less heavily overlaid with black, and the sides decidedly lighter; outersides of forearms white, or nearly pure white, instead of distinctly suffused with plumbeous; ears clothed with grayish, instead of dusky hairs, and tail grayer above near base; skull slightly different. Darker and more buffy than *P. b. hueyi*, and skull differing in minor details.

*Color.—Type:* Upper parts near pinkish buff (Ridgway, 1912), the top of head and dorsum moderately overlaid with black-tipped hairs, becoming thinner and less conspicuous on sides; a narrow, buffy lateral line present; under parts, fore limbs and hind feet white; ears thinly clothed with fine grayish hairs; tail above grayish brown near base, becoming purer brown toward tip, dull white below.

*Skull.*—Closely resembling that of *P. b. rudinoris*, but braincase narrower, the narrowing mainly in the parietals and interparietal; mastoids and auditory bullae rather small, but closely approaching those of *rudinoris*. Very similar to that of *P. b. hueyi*, but braincase and interparietal narrower; mastoid and auditory bullae slightly smaller.

*Measurements.—Type:* Total length, 198; tail vertebrae, 107; hind foot, 25. Average and extremes of three adult male topotypes: 194 (183–203); 108 (99–114); 25 (24–27). *Skull* (type): Greatest length, 29; greatest mastoid breadth, 14.3; zygomatic breadth, 15.5; interorbital breadth, 6.9; length of nasals, 10.2; width of nasals (in front of incisors), 2.9; interparietal, 6.1 × 3.4; maxillary toothrow (alveolar length), 4.5.

*Remarks.*—The range of *P. b. extimus*, embracing the lower elevations in the central and southern part of the peninsula, marks the extreme southern limit of the distribution area of the species as a whole. The new form differs mainly in light, buffy color from the distinctly darker subspecies *rudinoris* of the northwest coast region, and from the grayer race *hueyi*, inhabiting the desert region east of the San Pedro Martir Mountains. The cranial characters are slight and comparatively unimportant. Specimens from as far north as the Vizcaino Desert west of San Ignacio may be regarded as nearly typical. Those from farther north grade, along the eastern and western sides of the peninsula respectively, toward the more northern forms. Specimens from Punta Prieta on the western side near latitude 29° are rather dark and indicate an approach to *rudinoris*, but seem more properly assignable to the present form. Specimens from Calamahue and Onyx on the eastern side of the peninsular are near typical *extimus* in general color, but in somewhat broader skulls tend toward *hueyi*.

*Specimens examined.*—Total number, 54, all from Lower California as follows: Calamahue, 11; Calmalli, 3;[a] Comondú, 1; Matancita, 1; Onyx, 1;[b] Punta Prieta, 5;[b] San Bruno, 2; San Francisquito, 1; San Ignacio, 18;[c] San Ignacio (20 miles west), 4; San Jorge, 1; Santa Rosalia (10 miles west), 1;[b] Tres Pachitas (type locality), 5.

[a] Two in collection San Diego Society of Natural History.

[b] Collection San Diego Society of Natural History.

[c] Thirteen in collection Museum of Vertebrate Zoology; two in San Diego Society of Natural History.

ZOOLOGY.—*The demanian vessels in nemas of the genus* Oncholaimus; *with notes on four new Oncholaims.*[1] N. A. COBB, Bureau of Plant Industry.

Continuing the work of deMan, 1884, and zur Strassen, 1896, observations have been made on *Adoncholaimus fuscus* (Bastian), *Metoncholaimus pristiurus* (zur Strassen) and other Oncholaims (listed on p. 227) with particular reference to the system of tubular organs discovered by deMan. Building on the foundation laid by these eminent observers, it has been possible to define the demanian system, and, within limits, assign it a function. The following definition and table of homologous terms, together with the accompanying text appreciably advance our knowledge of this remarkable system of organs.

DEFINITION

*Demanian Vessels:*—In adult female nemas (Oncholaims) a complicated double system of efferent tubes; connecting, (1), with the middle or posterior part of the intestine through an osmosium (see p. 230), and (2), with the uterus (or uteri); these two efferents being confluent at a special glandular "gateway," the uvette (see p. 229), and emptying thence backward and outward, through one or two ducts having more or less moniliform affluent glands (see p. 228, Fig. 1). Normally, the ducts lead to exit pores in the body wall, usually laterad, one or more on each side, near the base of the tail.

In certain cases at least, apparently homologous tubular organs connect with the gonad of the male near the beginning of the *vas deferens*. For example, in *Metoncholaimus pristiurus*, *Adoncholaimus fuscus* and *Oncho-*

[1] Investigations carried on in part at the U. S. Fisheries Biological Station, Woods Hole, Mass. The abbreviations used are mostly self-explanatory; e.g. *onch dsl*, (*onchium dorsale*), dorsal tooth. Received May 15, 1930.

*laimium appendiculatum* I observe a tubular glandular vessel, outstretched forward and emptying backward into the *vas deferens*, that appears homologous with parts of the better known demanian system of the females. See Fig. 2.

In female nemas the functioning demanian vessels (e.g. *pristiurus*) elaborate a copious, elastic, sticky, non-water-soluble, nearly colorless secretion, possibly utilized ("spun"?) during agglomeration and copulation, and also presumably to protect and preserve the batches of eggs after deposition and during segmentation.

The demanian organs seem to prevail in mud-inhabiting, and sand-inhabiting oncholaims,—i.e. those of stagnant habitat; and to be absent or less prevalent in oncholaims living in more thoroughly oxygenated water,—on the surface of eelgrass, and among algae, e.g. in *Prooncholaimus* Micoletzky, 1924.

*Origin.* As to the primitive nemic tissue from which the demanian vessels may have originated, we seem driven to accept the primitive gonadic tissue as the probable source. The histology of the demanian system reminds one most strongly of the structure of nemic gonads; most of the histological elements known in the demanian system have homologues in the gonadic system of nemas;—while on the contrary there is no such tunic, and there are no such forms of nuclei, known in connection with the enteron.

Equivalent terms of various authors

| Author, de Man | Author, zur Strassen | Author, present |
|---|---|---|
| Röhrenförmiges Organ<br>Organe tubiform | Röhrenförmiges Organ | Demanian System |
| Hauptrohr (fuscus)<br>Canal principal (albidus) | Stammrohr | Enteric efferent |
| Verbindung zur Stütze<br>Blindes Vorderende | Offene Verbindung<br>Mündungsorgan | Osmosium, or Selective demanian intake (enteric) |
| Verbindungsröhrchen zwischen Warze und Uterus<br>Tube de communication | No mention | Uterine efferent |
| Ausführungsgang in den Uterus | Blindgeschlossener Sack | Demanian intake (uterine) |
| Warze<br>Papille ovulaire | Rosette | Uvette |
| Rothbraune drüsen (fuscus)<br>Tubes latereaux (albidus) | Endschlauch des Rohrorgans | Moniliform Glands |

## DIAGNOSES OF THE GENERA AND SPECIES MENTIONED HEREIN

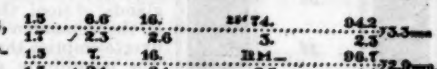
### ONCHOLAIMINAE Filipjev, 1918 and 1925

(but without Anoncholaimus, Pelagonema, Anoplostoma, Trilepta, Krampia, Filipjevia.)

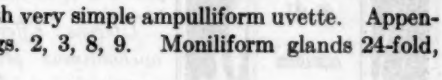
## *ONCHOLAIMIUM*, n. gen.

Monodelphic Oncholaiminae with demanian system, whose males have a versatile, preanal, ventral appendicule. See Figs. 2 and 3.

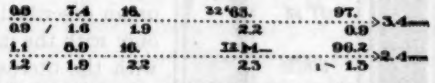
*Oncholaimium appendiculatum*, n. sp. Oncholaimium with apparently deteriorated moniliform glands without exit pores, and with very simple ampulliform uvette. Appendicule "hinged" and mobile. Figs. 2, 3, 8, 9. Moniliform glands 24-fold, (8 + 16). Exceptionally 32-fold.



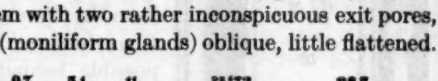
*Oncholaimus nigrocephalatus* n. sp. Oncholaimus with very slightly compound, non-refractive uvette, pigmented head, and hemispheroid, immobile, preanal, ventral male supplement; demanian system with two rather inconspicuous exit pores, each laterad; cells of the rouleaux (moniliform glands) oblique, little flattened.



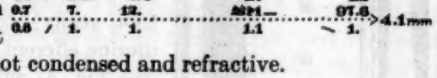
*Oncholaimus serpens*, n.sp. Oncholaimus whose moniliform glands are vaguely seriated but not in rouleaux. Compound uvette not condensed and refractive.



*Metoncholaimus pristiurus* (z. Str.). Specimens from Woods Hole gave the opposite measurements. Moniliform glands 64-fold.



*Adoncholaimus panicus*, n. sp. Adoncholaimus having a transverse row of seven demanian exit pores on each side. See Fig. 7.



*Adoncholaimus fuscus* (Bast.). Moniliform glands 8- or 16-fold,—see Fig. 1.

One soon appreciates the weight of zur Strassen's words where he says, in speaking of the demanian system of various oncholaims,—"In fact, the differences are such that, were they equally pronounced in any other system of organs, they would lead to the proposal of separate genera, or even families."

In this connection the present studies lead to the belief that the demanian system not only varies markedly in the different groups of oncholaims, but that in all probability the system is present but has been wholly overlooked in many of the forms described. Hence it seems premature to attempt a complete subdivision of the oncholaims into genera and subgenera. It may be doubtful whether the genera and subgenera so far proposed are natural ones. In particular, *Oncholaimus*, the group connected with the type species *attenuatus*, seems chaotic; yet no better course appears, at present, than to leave *serpens* and *nigrocephalatus* in this ill defined group.

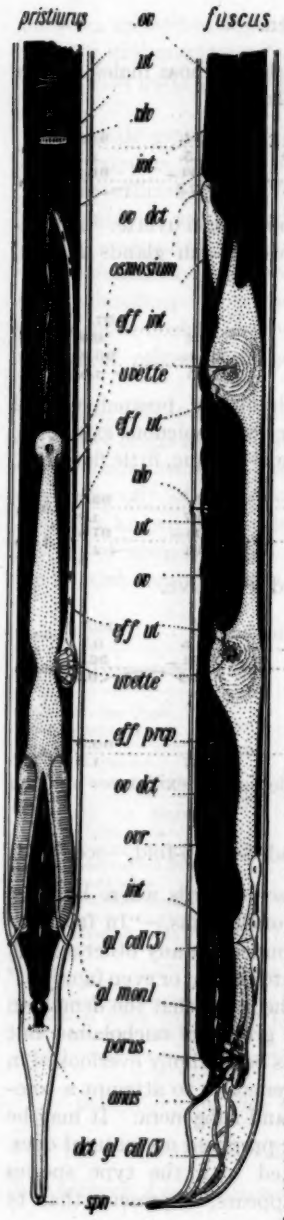



Fig. 1. Amended diagrams of the demanian system of *Metoncholaimus pristiurus* (dorsal view) and *Adoncholaimus fuscus* (side view), modified from the diagrams of zur Strassen and deMan respectively. *eff int*, enteric or intestinal efferent; *eff ut*, uterine efferent; *vlv*, vulva; *ov dct*, oviduct; *gl cdl* (3), the three caudal glands; *gl monl*, the moniliform glands; *porus*, exit pores of the demanian system. Notice that in each case the uvette empties through a minute pore, the uvette pore. The moniliform glands in *pristiurus* are 64-fold; in *fuscus* 8- or 16-fold.

*Uterine Efferent.* An examination of *Metoncholaimus pristiurus* (zur Strassen) furnishes convincing evidence that the interesting female organ described by zur Strassen is connected not only with the intestine, as he discovered, but also with the uterus by means of a tube (see *eff ut*, Fig. 1) extending forward from the uvette,—i.e. from the "rosette" of zur Strassen. The evidence is as follows: In many female specimens it is possible behind the vulva to follow backward from near the vulva a long, narrow, apparently (not really) *vacant space*, reminiscent of the uterine efferent of *Oncholaimium appendiculatum* (see Fig. 3) which on more careful examination proves to be a duct. This duct, however, is not so refractive or of such uniform diameter as in *appendiculatum*, and is even more difficult to see. It varies slightly in diameter. Here and there throughout its length it can be seen to have a thin, double-contoured wall containing small but definite, much elongated nuclei. This tube is usually in a collapsed condition, more often presenting its edge toward the observer, but sometimes not. When it is presented edgewise, one may often detect in its thin wall the scattered elongated nuclei, especially in specimens fixed and stained in acetic acid methyl green; occasionally nuclei can be seen also in other views Examining the requisite number of specimens leads to the conclusion that from the uterus near the vulva the duct arises dorsad as a broad tube, directed backward, which narrows rapidly and extends along the right side of the nema,—approximately along the right lateral chord though not necessarily exactly opposite,—and, expanding, joins and envelopes the uvette. See Fig. 1

*Uvette**. The "warze" of deMan,—i.e. the "rosette" of zur Strassen,—is the structure to which I apply what seems the more appropriate name "uvette." Comparisons show that, notwithstanding the very marked differences in form, the various organs herein called uvettes are homologous; the same is true of those called moniliform glands.

The uvette of *Adoncholaimus fuscus* (Bastian) as illustrated by deMan probably presents 32 elements (Körnchen, deMan's Fig. 29) as does that of *M. pristiurus;* these elements have been outlined by deMan and figured somewhat more in detail by zur Strassen (deMan's Figs. 24, 29; zur Strassen's Figs. 13, 14).

In favorable specimens I have seen the uvette of *fuscus* to be a "radial" structure made up of about 32 elements surrounding a minute pore, somewhat as in the uvette of *pristiurus,* (See Fig. 1) but the elements here are far less refractive. *Rarely* can one see the appearance illustrated by deMan in his figure 29; whereas the appearance he does not satisfactorily illustrate,—a very complicated one, by the way,—is the usual appearance; and when this appearance is more pronounced, commonly the minute refractive "Körnchen" that deMan figures are not to be seen, or only some of them faintly. DeMan's "Kugel," figured by him as if nearly round, I find seldom round or ball-shaped; frequently it is so "collapsed" (?) as to be difficult to see at all, and it is more likely to be elongate or ellipsoidal, or perhaps flattish-ellipsoidal, than to be equidiametral as shown in deMan's Fig. 29.

DeMan does not give a thoroughly satisfactory description or figure of his "Warze." In one of his figures (Fig. 29) I count 33 minute, circular, dot-like elements where he makes his "Verbindungsröhrchen" join the "Warze." Occasionally I also see this appearance, and with about the same number of elements (32?). It is difficult to say as yet what the exact function of the uvette is, but it seems a regular, doubtless glandular, component of the demanian system. In *Oncholaimium appendiculatum* the uterine vessel, extending backward from the uterus, nearly as described for *pristiurus,* finally expands a trifle into a small, often rather indefinite, ampulliform uvette of the very simplest character, which joins the right subdorsal of the two longitudinal series of cells,—the moniliform glands,—by means of a minute refractive pore,—the uvette pore. See *uv,* Fig. 3. In *Oncholaimus nigrocephalatus* the uvette, which in *O. appendiculatum* appears as a *simple* ampulla, becomes somewhat compound; that is to say, two additional or subordinate elements occur, one on either side of the main "ampulla," so that the whole is rather obscurely triplex.

In another oncholaim, *Oncholaimus serpens* n. sp., the uterine tube extends backward just as definitely as in *Oncholaimium appendiculatum* and joins the rest of the demanian system in the form of an expanded and much larger

* Uvette; a diminutive cluster. From latin, *uva,* a cluster of grapes.

uvette, rather closely resembling one of the uvettes of *Adoncholaimus fuscus*. In *O. serpens* the elements are not nearly so refractive, and the somewhat pyriform whole is not so symmetrical; but it is made up of radiating elements having some resemblance to those composing the uvette of *pristiurus*.

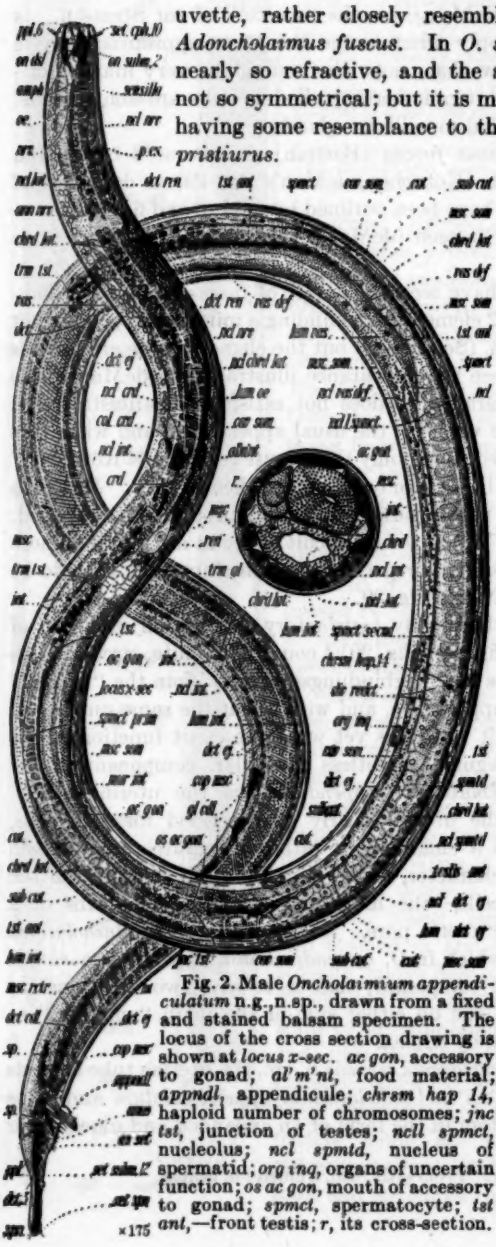



Fig. 2. Male *Oncholaimium appendiculatum* n.g.,n.sp., drawn from a fixed and stained balsam specimen. The locus of the cross section drawing is shown at *locus x-sec*. *ac gon*, accessory to gonad; *al'm'nt*, food material; *appndl*, appendicule; *chrsm hap 14*, haploid number of chromosomes; *jnc tst*, junction of testes; *ncll spmct*, nucleolus; *ncl spmtd*, nucleus of spermatid; *org inq*, organs of uncertain function; *os ac gon*, mouth of accessory to gonad; *spmct*, spermatocyte; *tst ant*,—front testis; *r*, its cross-section.

*Osmosium. Moniliform glands.* In addition, I have established to my satisfaction that the main tube of the demanian system in *Adoncholaimus fuscus*, which was described by deMan as probably being merely fastened anteriorly to the intestine, and therefore regarded by him as probably merely a holdfast, is in reality in communication with the intestine by means of what I have called an *osmosium*.* It has much the same structure as that described by zur Strassen for *Metoncholaimus pristiurus* and *M. deMani* (zur Strassen, Figs. 4 to 12),—and which I have examined in *pristiurus*,—*except that there is no open communication*. There are no essential differences in the structure of the enteric junctions of the

*Osmosium; that part of an emunctorium or analogous organ through which, mainly by osmotic action, soluble matter is transferred from one organ to another. The osmosium is here not emunctorial. It is still doubtful whether the osmotic cells in this particular case are of enteric or demanian origin. While the staining of these cells seems to favor demanian origin, the structure seems to favor enteric origin.

various oncholaims I have examined, except minor ones in the more or less, but very obscurely, radiating part that sets into the wall of the intestine. This part forms an "osmotic" exit *through the the intestinal wall* in the shape of special, presumably metabolic and at least selective, glandular tissue of the osmosium.

In the species *Oncholaimus nigrocephalatus* there are external lateral exit pores in the anal region much as in *pristiurus* but they are minute. Thus far, however, I have searched in vain for these pores in *Oncholaimium appendiculatum*.

In this latter species there are two moniliform subdorsal series of 24 cells each which I propose to call moniliform glands. These are rather close homologues of the 64-fold rouleaux of zur Strassen; less obviously, of the 8- or 16-fold "Rothbraune drüsen" of deMan. The uterine vessel joins the right hand one of these moniliform glands, as is shown near the middle part of figure 3 on this page, at *uv*.

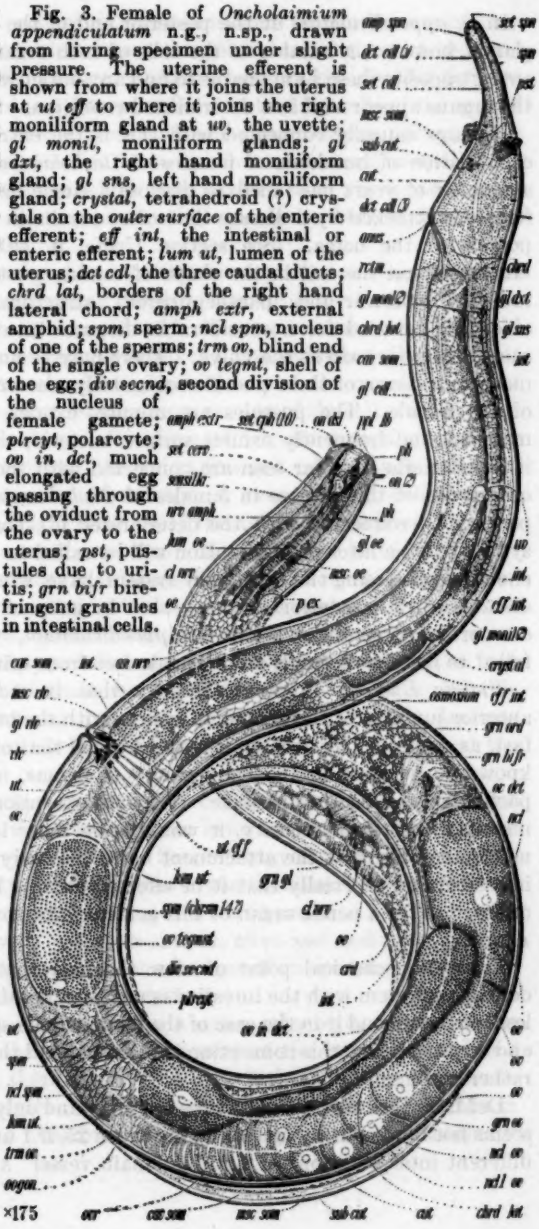



Fig. 3. Female of *Oncholaimium appendiculatum* n.g., n.sp., drawn from living specimen under slight pressure. The uterine efferent is shown from where it joins the uterus at *ut eff* to where it joins the right moniliform gland at *uv*, the uvette; *gl monil*, moniliform glands; *gl dxt*, the right hand moniliform gland; *gl sns*, left hand moniliform gland; *crystal*, tetrahedroid (?) crystals on the *outer surface* of the enteric efferent; *eff int*, the intestinal or enteric efferent; *lum ut*, lumen of the uterus; *dct cdl*, the three caudal ducts; *chrd lat*, borders of the right hand lateral chord; *amph extr*, external amphid; *spm*, sperm; *ncl spm*, nucleus of one of the sperms; *trm ov*, blind end of the single ovary; *ov tegmt*, shell of the egg; *div secnd*, second division of the nucleus of female gamete; *plrcyt*, polarcyte; *ov in dct*, much elongated egg passing through the oviduct from the ovary to the uterus; *pst*, pustules due to uritis; *grn bifr* birefringent granules in intestinal cells.

In *O. appendiculatum* at the posterior end of the two 24-cell moniliform glands, however, a number of the cells of each organ seem *loosened from the series;* opposite these I am unable to find any outlet whatever;—that is to say, the organs appear as if in a deteriorated condition. See *gl dxt, gl snst,* Fig. 3.

Perhaps causally connected with this is the extraordinary fact that the examination of hundreds of females of *Oncholaimium appendiculatum* over a number of years has failed to disclose a single healthy specimen. Every female is attacked by a disease that often results in necrosis of the posterior portion of the nema. (See section *Uritis,* p. 240). The disease (uritis) breaks out on the tail in the shape of minute pustules having an internal radiated, or linear and "parallel-fibered," structure, *pst,* Fig. 3, sometimes extending forward for a considerable distance into the nema,—in extreme cases, as far forward as the vulva. There may be one, two, three, or even as many as a dozen of these pustules irregularly scattered on the posterior part of the female. The pustules are minute, exude, *inter alia,* an insoluble material, and frequently exhibit surface bacteria, though it seems doubtful if the bacteria thus far seen are connected with the disease. The uniform occurrence of this disease in females of *Oncholaimium appendiculatum* may perhaps be connected with the deteriorated (?) condition of the demanian system. On a later page attention will be called to the fact that other oncholaims possessing the demanian system have what appear to be similar diseases of the posterior extremity; but in none of them is there any such extraordinary condition as in *O. appendiculatum,* where examination has failed to disclose a single adult female free from uritis.

*Enteric Efferent.* Against the idea that in *Adoncholaimus fuscus* the anterior junction of the demanian system with the intestine is merely a holdfast, as suggested by deMan, it may be urged that of other elongated organs known to lie loose in the body cavity of nemas, none are secured in this particular way to the intestine. Why an exception in this case? If it is merely a matter of security, it would seem more in harmony with known nemic anatomy that the attachment be to the body wall rather than to the intestine, and especially that it be effected along a lateral chord. It is not unheard of for a nemic organ of this general form to be attached to a lateral chord.

From a mechanical point of view the idea that the connection of the demanian system with the intestine is merely a holdfast seems to have all the less to recommend it in the case of the monodelphic species, such as *pristiurus* and *serpens,* where this connection is so far caudad that such a holdfast seems rather needless.

DeMan's idea that his main tube is simply and only *fastened* to the intestine seems not borne out by facts; and his figure 25, if I understand it, admits of a different interpretation. I find his "main vessel" anteriorly to be *hollow to*

*ils very end*,—the "blind end" of deMan,—and that the freely moving contents of the tube are visible clear to what might be called the surface tissue of the intestine (*tissue of the intestine altered, to be sure*). DeMan's figure 25 seems easily to admit of this interpretation. I find the cells of the wall of the intestine (if they be really intestinal) are altered where the vessel is attached, and this fact suggests that we have here modified selective tissue,—the osmosium,—the function of which is to extract from the intestine and usher into the demanian system, presumably mainly by osmosis, a product utilized by the latter.

May not the evidence offered by zur Strassen for an *open* communication between the enteric efferent and the intestine in *pristiurus*,—i.e. the evidence of his microtome sections,—be capable of a different interpretation? Could zur Strassen's sections have been deceptive? The published figures of his "open connection" between the demanian system and the intestine are not satisfying, in that they appear to show a large portion of the cell walls missing. Now *pristiurus* ingests mud, and, in consequence, its intestine *normally contains much fine grit*. Is it not likely that this grit, acting as it naturally would during the sectioning, would damage, or even destroy, delicate cells that, before being broken, might have *closed* the aperture which zur Strassen shows and describes as an open connection? The suggestion is that this might occur, at the time the sections were cut, through the combined abrasive action of the grit and the coincident dulling of the microtome knife. All zur Strassen's figures show the intestinal lumen more or less *open;* but when the intestine is entirely empty and free of grit *it is collapsed, not open*, so that the lumen, in well made sections, is closed and difficult to see. May not this indicate that the vacant lumenal spaces shown in zur Strassen's illustrations probably *did* contain grit at the time of fixation, and hence, no doubt, at the time of sectioning?

*Pristiurus, fuscus* and some other mud-inhabiting Oncholaims can be kept alive in pure running sea water for days, or even weeks, and when so kept evacuate the intestine very completely. Sections may then be made without the interference of the grit normally present in the intestine. *I have not found such sections to present the appearance figured by zur Strassen.*

In an examination of very many specimens, alive and sectioned, I have never been able to convince myself of the existence of an open communication between the intestine and the demanian system.

Any such open connection would seem a grave menace to the well-being of the organism. For if the enteric intake were of the nature figured and described by zur Strassen, there would seem to be little or nothing to prevent the entrance into the demanian system of undigested detritus contained in the intestine, together with numerous living microorganisms which normally

constitute a very appreciable part of the feces. No such detritus is ever seen in the demanian system.

Furthermore, on examining living *pristiurus* and *fuscus*, both of which I find to occur along Cape Cod, U. S. A., I find that when the food in the intestine is moving rapidly back and forth opposite zur Strassen's supposed open connection, no portion of it ever enters the enteric efferent. There is not even the *slightest* corresponding disturbance of the *contents of the lumen* of the enteric efferent close by, which, as zur Strassen also points out, can be seen in the end portion of the demanian tube where it joins the surface of the intestine.

Possibly the analogous connection with the uterus is hardly to be taken as a very distinctly open one. True, I have seen cases in *pristiurus* where, when the *diseased* uterus was filled with microorganisms (microorganisms causing the disease*), the continuous mass of them *also filled the nearby part of the corresponding demanian vessel* in such a way that there *was* a direct "tubular" connection between the uterus and the vessel. Normally, however, the conditions are as follows:—One traces the uterine demanian vessel directly forward to the uterus, where its lumen continues for a short distance into a glandular tissue in the posterior end of the uterus,—zur Strassen's so-called "blind end, behind the vulva,"—and there ceases in the midst of a large number of uterine cells somewhat similar to many of those constituting the main portion of the wall, i.e. what seems to be a special collection of glandular uterine cells. In *fuscus* this same thing occurs where the oviducts join the proximal ends of the two uteri, not, as in *pristiurus*, at the posterior portion of the single uterus close to the vulva; the histology of this junction, however, is much the same in these two species. It is as if special uterine cells were devoted to secreting material to be delivered to the demanian system through the uterine efferent,—the "tube de communication" of deMan.

In *pristiurus* the long tubular vessel connecting the uterus with the demanian system,—the uterine efferent,—often is difficult to see, especially in its entirety. No better proof of this could be required than that it escaped so keen an observer as zur Strassen.

Even in *Adoncholaimus fuscus*, while the two short uterine efferents can sometimes be followed from the uteri to the main vessel of the demanian system, often it is practically impossible in a given specimen to follow them throughout their course. Knowing their locality and structure, one can usually determine how they lie and their probable limits, but that is about all. Of course, in a small minority of favorable specimens quite the contrary is true;—the entire tube can be made out satisfactorily as was first done by deMan.

* This disease appears to have nothing to do with uritis (see p. 240); uritis seems an entirely distinct disease.

*Direction of Flow in the Demanian System.* Evidently a considerable amount of matter is contributed by the intestine to the demanian system. Zur Strassen had no difficulty in assuming the *entire* amount to be so contributed in *pristiurus* (for he appears to have been unaware of the connection in *pristiurus* of the uterus with the uvette, and hence with the demanian system).

However, quite frequently in the contents of the enteric efferent of living *Metoncholaimus pristiurus* near and in front of the uvette pore, refractive, curved, wave-like effects are seen such as would be produced by the gradual mixing of two viscid fluids of unequal refractiveness,—an appearance that might readily be produced by the flowing of a liquid through the uvette pore from the uterine efferent into the enteric efferent in such quantity that some of it passed slightly forward,—perhaps through cover glass pressure.

On various occasions, I have seen a considerable quantity of matter in the main enteric vessel close to its junction with the intestine. While this is no proof that this matter was actually derived from the intestine, it is favorable to that conception. Such matter never contains intestinal debris,—nor sperms (see F. H. Stewart, 1906), nor pseudo eggs,—"balls of finely granular substance," (see zur Strassen.)

If the demanian system emptied *into* the intestine, it is to be expected that it would do so through an aperture, pore, similar to those of other affluent enteric glands,—those emptying into the oesophagus for instance. In nemas such pores are extremely small, have a definite refractive lining, and are adapted to check any "backwash" due to movement of the contents of the enteron,—e.g. just such a structure as occurs in the uvette of *pristiurus*. But no such pore has been seen in connection with any *enteric* demanian vessel.

Moreover, against the flow of any of the demanian fluids being *toward* the enteron, it may be urged that in *pristiurus* a special secretion is at times actually seen issuing rather copiously from the pores near the tail,—the external outlets of the demanian system,—and there is not the slightest reason to suppose that *in this region* the flow is ever anything but backward and outward. There is no evidence that the demanian system is, for instance, a water-vascular system; or that sea water is *taken in* through the antecaudal lateral pores.

Again, there is little if any reason to believe the demanian system accessory to digestion, because whatever digestive function would be advantageous to *adult* females would seem also to be advantageous to the young nemas; yet there are no such organs in young oncholaims, for they come into existence at the last moult. The same may be said of any supposable ordinary *excretory* function.

But if it be supposed that, for some unexplained reason, adult egg-producing females require to *excrete* (not secrete) matter peculiar to them, in other words that the demanian system, or some part of it, be a sort of temporary mal-

pighian system,—a rather violent supposition,—it would seem that the excretion, as such, if poured into the intestine at all, should be poured in *posteriorly*. But in didelphs,—*fuscus, panicus*,—such a supposition would pour it in near the *anterior* end. Or, if it be supposed that the demanian system is simply an emunctorium accessory to the intestine and *emptying outward and backward*, then why the attachment to the *fore* part of the intestine as in *fuscus*?

If the demanian system is excretory, then it is necessary to assume that the necessities of adult females in the way of excretion are different from those of the male or the young female. No reason has been advanced for such an assumption.

*Deduction by Elimination.* In the demanian system of *O. pristiurus* three ducts come together at a single point, indicated by X in figure 4,—ducts in each of which a fluid may conceivably flow in either direction; i.e., there are six different paths along which fluid may be conceived to flow. The assumption is, of course, that, when the organs are functioning normally, fluid passes *constantly in one direction only* in each of the three tubes, 1, 2, 3, Fig. 4.

Fig. 4. Diagram of the six possible currents.

Indicating the six possible paths by arrows lettered *a*, *b*, *c*, *d*, *e*, *f* (Fig. 4), mathematically, there are twenty possible combinations in groups of three as follows:

*abc, abe, acd, acf, adf, bde, cde, cef, bef, bcf. abd, abf, ace, ade, bcd, bdf, cdf, aef, bce and def;*— this is according to the formula for combinations,

$$\frac{n(n-1)\ (n-2).....(n-r+1)}{r!} = \frac{6 \times 5 \times 4}{3 \times 2 \times 1} = 20, \text{ when } n = 6 \text{ and } r = 3.$$

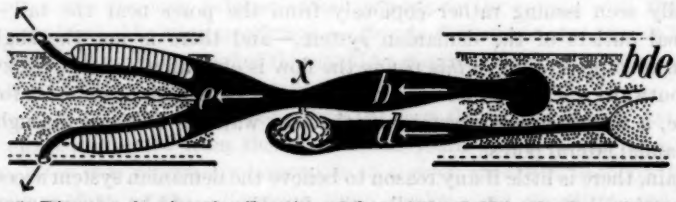


Fig. 5. Diagram showing the direction of flow of the fluid in the demanian system. The intestine and the posterior end of the uterus are shown near *bde*. The backward flow of the fluid in the enteric and uterine efferents is indicated at *b* and *d*, and the backward flow of their combined products at *e*. The outward flow of the fully elaborated secretion after it has passed the moniliform glands is shown by the two oblique black arrows.

It is evident that a combination containing *a* and *b* represents a physical impossibility, i.e. represents opposite currents simultaneously in the same duct,—duct number 1; and so with combinations containing *c* and *d*, and *e*

and *f*. (It is theoretically possible, of course, that the same tube might have a flow in one direction at one time and in the opposite direction at another time, but, physiologically speaking, this is an unusual occurrence, and practically an unheard of thing in a tubular organ "open" at both ends). We may therefore eliminate from the 20 possibilities, 12 of the combinations, leaving eight,—*acf*, *adf*, *bcf*, *ade*, *bce*, *bde*, *bdf* and *ace*.

But there are also two more combinations that obviously must be left out, as involving physical and physiological impossibility, namely *ace* and *bdf*, i.e., the cases where the three currents would simultaneously come to, or radiate from, the point X; *bdf*,—(no outlet, or reservoir), and *ace*,—(no obvious source of supply). This leaves six combinations possibly worthy of discussion, *acf*, *adf*, *bcf*, *ade*, *bce* and *bde*. These six possibilities are diagrammed in figures 5 and 6. Five of these possibilities (Fig. 6) are rendered

I. No exit pore for *a;* pore of uvette indicates reverse of *c; f* doubtful because entrance of sea water is possibly involved, while outflow of secretion is known from lateral pores, *p*.

II. No exit pore for *a; f* doubtful as in I; moniliform glands are believed here to empty outward because of their form and location in *O. fuscus;* only outlet of *d* and *f* would be through *a*.

III. *c* doubtful as in I; *f* very doubtful as in I and II; the only outlet for *f* and *b* would be through the uvette and *c*,—reverse of direction indicated by structure.

IV. No exit pore for *a;* the only source of *a* would be *d* and the uvette.

V. *c* doubtful as in I; *c* may also be reasoned against on the basis of homologous structures in *O. nigrocephalatus* and *O. appendiculatum*.

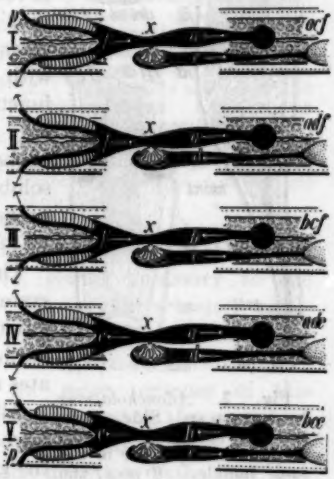



Fig. 6. Five diagrams of supposed currents in a demanian system. Objections to each supposition are listed opposite its diagram. *Compare with Fig. 5.*

exceedingly improbable by the physiological and morphological considerations listed opposite their diagrams. We may therefore safely deduce, even from this single discussion, that the flow is almost certainly as shown in Fig.5.

The significance of seven exit pores on each side in *panicus* (see Fig. 7) is an interesting subject for speculation. It can hardly be said that the existence of seven pores is for the purpose of furnishing a large outlet; it would seem much simpler to attain such a result by having a larger single pore. Nor

does it seem that the multiple outlet would have anything to do with the *quality* of the secretion that is prepared. The most reasonable supposition is that, in use, the demanian secretion is rendered more effective through a multiple delivery, and it is not difficult to reason out why this might be so.

Take, as a basis of reasoning, the fact that spiders have multiple spinneret tubes. This plurality is an advantage in that if some tubes of the spinneret apparatus do not act, or are restrained from acting, the remaining ones may continue to act, an economy of a kind often seen in nature. Thus threads of varying size and composition can be "spun." It seems not unlikely that the multiple thread of the spider may have structural advantages; at any rate it is a fact that, in some cases at least, the thread can be artificially split into components harmonizing in number with the elements of the spinneret apparatus. If these be advantages, it is quite conceivable that they may apply in some way to the multiporous *Adoncholaimus panicus*, and this would harmonize with the previous conclusions concerning the function of the demanian system;—for presumably the secretion in *panicus* is like that of other oncholaims, i.e. a copious, sticky, non-water-soluble, elastic material;—at least these are its properties after it is delivered into sea water by *pristiurus*.

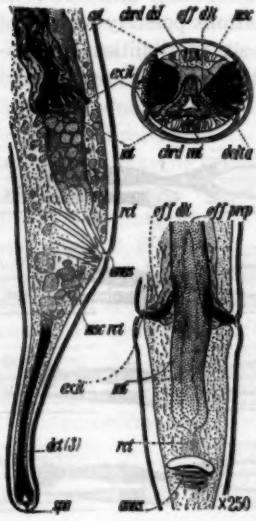



Fig. 7. *Adoncholaimus panicus* n.sp. Side, ventral and sectional views of the posterior portion of the same female. *eff prcp*, the principal efferent at the point where it forks to produce the two deltic efferents, *eff dlt;* the seven-fold delta is shown at *delta* and the seven exit pores at *exit*.

The location of the outlets of the demanian system is always well caudad, and the oncholaims having the system are agile and limber, all of which harmonizes with the belief that the system elaborates material used with some degree of "skill."

All oncholaims having the demanian system have a habit of coiling and uncoiling and can with the greatest ease place the exit pores of the system against any part of the body except the tail and its immediate vicinity, and this habit, no doubt, is correlated with the function of the secretion. Females of such oncholaims *have relatively short tails*,—as if longer ones would perhaps be in the way.

Conceivably, of course, the demanian secretion might have properties attractive to the other sex (odor, etc.), but the idea does not seem to appeal so strongly as that of having something to do with other matters.

In this connection it may be recalled that, opposite the demanian exit pores of *Metoncholaimus albidus* (Bastian), deMan described and figured a persistent girdle of left-over yellowish brown secretion.

Oncholaims having the demanian system, at least most of them, have a way of collecting together in masses when artificially assembled in sea water. Conceivably this habit may have some connection with the demanian secretion, but it is not obvious why *only adult females* should secrete for this purpose alone.

The demanian system appears more distended when the uterus is full or nearly full of eggs. For instance, at this time the uterine efferent and portions of the uterus of *pristiurus* may contain an abundance of colorless, transparent, rather structureless-looking matter, resembling, under the microscope, partially dissolved shavings of gelatin.

The question arises as to what becomes of the secretion of the accessory gland of the male, which is possibly or probably a homologue of the demanian system in the female. No reply to this question has occurred in connection with these investigations except the possibility, which seems remote, that the "gum arabic-like" mixture sometimes seen in the uterus of *pristiurus* might possibly have been derived wholly or in part from the male. It should perhaps be mentioned that in the nemic genus *Rhabditis*, glands accessory to the male gonad are known that secrete a copulatory cement; but no such cement is yet known in connection with any oncholaim.

Fig. 8. Profile of head end of male *Oncholaimium appendiculatum*. The three onchia are shown; the left ventral submedian is the longest,—see *on dsl* and *on subm* (*2*). The sensilla and amphidial nerve are shown. Nuclei shown mostly central nervous system; the scattered darker ones are nuclei of the lateral chord, the width of which is pointed out at *chrd lat*.

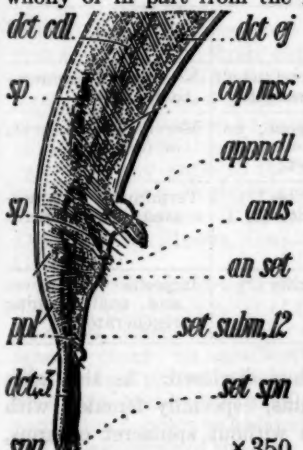



Fig. 9. Tail, male *Oncholaimium appendiculatum*. *ppl*, single ventral papilla; *dct* (*3*), caudal ducts leading to spinneret; *appndl*, ventral, erectile appendicule; *an set*, anal setae; *set subm* (*12*), submedian setae on male only.

Of course, the mere presence of this material in the uterus and in the portion of the uterine efferent nearby does not of itself indicate the direction of the flow, but the structure of the organs distinctly suggests that the flow is caudad, i.e. from the uterus toward the external openings near the tail. Were the entire flow of the demanian system toward the uterus, it would seem strangely circuitous.

While the fact that no external exit pores have been discovered in *Oncholaimium appendiculatum* makes conceivable a flow from its enteric vessel and the moniliform glands through the uvette to the uterus, yet the structure of the uvette pore seems as dis-

tinctly adapted to a flow in the opposite direction, i.e. caudad, in this species as in the others. Moreover a different explanation of this exceptional case seems more plausible, namely, that in *O. appendiculatum* the demanian organs are in a deteriorated condition. The fact that this species is the only one that *almost invariably* presents disease in the posterior extremity of the adult females may harmonize with the supposition that the demanian system of this species is in a deteriorating and perhaps useless condition. The nonconsecutiveness of the posterior cells of the moniliform glands in *O. appendiculatum*, and the appearance of crystals on the outer surface of the enteric efferent, (Fig. 3) suggest decadence in this anomalous species.

In *O. appendiculatum* the uvette is reduced to a mere ampulla; and is almost as greatly reduced in *nigrocephalatum*. In neither of these is it at all likely that the uvette itself could produce any very appreciable secretion flowing into the uterus, and yet in both species the uterine *tube* is better developed (or at any rate more obvious) than it is, for instance, in *pristiurus*, where the uvette is strongly developed.

I have not seen sperms, or anything remotely resembling them, in the demanian system, as reported by Stewart and zur Strassen.

*Uritis.* It is interesting that the females of a number of oncholaims shown to possess demanian vessels seem unusually subject to disease.

Among such oncholaims, allusion is made to the following typical cases:

| Name | Location | Lesions | Regeneration |
|---|---|---|---|
| ? | Woods Hole, Mass., U. S. A. | "tailless" | Undoubtedly healed over |
| *O. appendiculatum* | Woods Hole, Mass. | From tail end to half of nema necrotic | No signs of regeneration |
| *M. pristiurus* | Woods Hole, Mass. | Tail end gone; no anal opening; no spinneret | Merely healed over; no openings |
| *A. fuscus* | 1. Cape Cod, Mass.<br>2. Miss E. Horsman Univ. College of Wales | Former uritis (?)<br>Former uritis (?) | Terminus regenerated; no spinneret |
| *New Oncholaim* | Florida, U. S. A. | Former uritis (?) | Imperfect spinneret and anal opening regenerated |

An interesting morphological problem is thus disclosed. As the table indicates, one not infrequently finds oncholaims, especially females, with highly peculiar caudal extremities,—sometimes without spinneret or anus, sometimes with these organs present but apparently abortive, or at least peculiar in form,—abnormalities probably due to specific disease. Apparently the disease is sometimes combated by the nemic organization, so that the posterior end of the nema heals over, and in some cases it seems as if a new

anus is formed, and possibly even a new spinneret! Just how this occurs is not yet clear,* but I have seen both deformed anal openings and deformed spinnerets of female oncholaims that appeared to give evidence of having been imperfectly regenerated after some accident, or, more likely, after uritis.

# PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

## GEOLOGICAL SOCIETY

### 461ST MEETING

The 461st meeting of the Society was held in the Assembly Hall of the Cosmos Club, February 26, 1930, President G. R. MANSFIELD presiding.

The Secretary announced the election of Mrs. CHARLES D. WALCOTT and Miss M. D. FOSTER, the latter of the U. S. Geological Survey, to Active membership in the Society.

*Informal communications:* E. F. BURCHARD showed lantern slides of a lens of intraformational conglomerate in the Cambrian Conesauga limestone in Alabama. This consists of flat plates of limestone, variously oriented in a matrix of more siliceous limestone. The plates of limestone are sharp edged and apparently have suffered no abrasion or transportation, but were cemented nearly in situ, soon after they were broken apart. He suggested that this deposit may have originated as talus filling of a small gully and showed a lantern slide of the present-day deposition of similarly shaped blocks of sandy clay at the base of an overhanging cliff in the Ackerman formation of Eocene age in Mississippi.

T. S. LOVERING described the three possible types of surfaces of no distortion and maximum strain obtained by compressing a sphere of reference into a strain ellipsoid. He pointed out that T. A. LINK in a recent discussion of the strain ellipsoid used a sphere of reference, the diameter of which shortened with the compression to equivalence with the intermediate axis of the strain ellipsoid. With this "Link" sphere of reference, the surfaces of no distortion can be at any angle to the applied force. LINK's treatment seems without mechanical or geological significance.

*Regular Program:* T. S. LOVERING: *The Tertiary history of the Front Range.* Discussed by Messrs. GILLULY, MERTIE, LOVERING, RUBEY, WERNER and GOLDMAN.

ROBERT BALK, *Structural survey of the Adirondack anorthosite.* (illustrated). The pre-Cambrian rocks of the Adirondack Mountains, New York, consist of an oldest system of marbles and schists—the Grenville formation—and three igneous rocks—an anorthosite, a gabbro and a syenite series. The anorthosite forms a central massif which is surrounded by the syenite, and the gabbros form hundreds of small round areas in the whole region. The Grenville formation appears as isolated fragments in the intrusive rocks.

The geologists of the New York State Geological Survey have held that the three igneous rocks crystallized from three independent molten magmas and that the order of intrusion was (1) anorthosite, (2) syenite series, (3) gabbro.—In 1917, N. L. Bowen maintained that anorthosite and syenite are co-mag-

* Regeneration seems to be uncommon in nemas.
Additional articles consulted—see zur Strassen's bibliographic list, 1896.

matic rocks, the anorthosite representing a residue of solid crystals which had precipitated in the parental magma, while the syenite was considered the mother liquor. The resulting controversy in the literature indicates a certain scarcity of structural data which the speaker has tried to supply through special studies in the field. The results of his studies are:

The anorthosite, the gabbro and the syenite series are all members of one and the same parental magma. Forty-seven examined gabbros grade into anorthosite or syenite, and no intrusive contacts have been seen. Gabbros have developed in the parental magma through clustering and accretion of solid ferromagnesian minerals, due to frictional forces between the individual crystal grains. The process begins with small lumps, leads to lenses and layers, and ends with spherical bodies as large as two miles in diameter. The larger gabbros have settled with reference to the surrounding magma, the smaller ones have not.

The anorthosite originated through accumulation of solid labradorite crystals in the magma chamber, as Bowen has maintained. The syenite is not, as a rule, intrusive into the anorthosite but grades into it; there is good evidence that it is the mother liquor of the parental magma which has been squeezed out from a central crystal-filled chamber into the surrounding Grenville formation where the syenite forms a multitude of sill-like masses.

The anorthosite is very likely a lens tilted to the northeast at 30°. Both indirect and direct observations point to this fact.

It is believed that a parental magma of unknown composition, but possibly resembling that of a quartz diorite, advanced from "under the edge of the Canadian Shield" obliquely to the southwest into the Grenville formation. This magma must have carried considerable quantities of solid labradorite crystals in suspension, and the following processes are thought to have occurred at the same time: (1) clustering and gathering of dark silicates forming spherical gabbros; (2) compacting and clustering of solid labradorite crystals, coalescing finally into a large lenslike mass (the anorthosite massif), with portions of mother liquor enclosed here and there; (3) ejection of the syenitic mother liquor into the Grenville formation, possibly as far as 30 miles away from the anorthosite.

The arrangement of the primary joint systems is in harmony with this general conception of the origin of the intrusive rocks. (*Author's abstract.*)

### 462ND MEETING

The 462nd meeting of the Society was held in the Assembly Hall of the Cosmos Club, March 12, 1930, President G. R. MANSFIELD presiding.

The Council announced with regret the deaths of CLAUDE E. SIEBENTHAL, former geologist of the U. S. Geological Survey, and Capt. H. A. C. JENISON, formerly of the U. S. Geological Survey, both Active Members of the Society.

*Informal Communications:* DAVID WHITE exhibited samples of brine from a bore hole in San Mateo, California, which have been shown to contain living bacteria, (*Micrococcus littoralis*) in sufficient abundance to give a brownish-wine color to the brine. A possible similar organic source is suggested for the reddish color of some salt deposits. Discussed by M. I. GOLDMAN.

*Regular program:* G. R. PUTNAM: *Isostasy.* Discussed by Messrs. LOVERING, SWICK, WHITE, RUBEY, A. C. LANE, and SPENCER, with reply by Mr. PUTNAM.

D. F. HEWETT: *Genesis of iron-manganese carbonate concretions in Central South Dakota.*—Recent explorations on a zone of iron-manganese carbonate concretions in Central South Dakota not only indicate the existence of a large quantity of low-grade manganese-bearing material but throw light on the chemical processes involved in their genesis. Natural exposures indicate that the zone persists for at least 40 miles along the Missouri River, but explorations have been confined to about nine townships near Chamberlain, Brule County. The zone is 38 feet thick and lies in the Pierre shale about 130 feet above the Niobrara limestone. Within this zone, the nodules range from 1 to 8 inches in diameter and tend to occur in persistent layers. Most of the nodules have grown around organic remains, largely shells of *Inoceramus*, but, in part, fragments of plants and of bones belonging to marine as well as terrestrial vertebrates. Explorations include 12 shafts that range from 32 to 48 feet deep and one open cut. In excavating these shafts, all of the nodules were separated from each 5-foot zone of shale, crushed, sampled, and analyzed. From five shafts, average samples of shale were collected from successive 10-foot zones and analyzed. On the average, each cubic yard of material excavated yielded 164 pounds of concretions containing 15.7 per cent manganese and 11.1 per cent iron.

In reviewing this large amount of analytical data, it was found that (1) the combined percentages of iron and manganese tended to be constant at 28 to 30 per cent and (2) as the weight of nodules recovered per cubic yard of shale increased, the percentage of iron in the sample of the nodules increased also. From this relation, it was inferred that the outer zones of the nodules contained more iron than the inner and this was confirmed by analyses of four carefully selected samples from a nodule. The ratio of the iron to the manganese content was about twice as much in the outer zone as in the inner zone. Further, for four of the shafts for which analyses of shale were also available, after calculating the amount of iron and manganese in the combined nodules and shale for successive zones, it was found that, although the amount of manganese per unit section was about half that of iron, the percentage of the total amount of manganese now found in the nodules was about twice the per cent of the iron.

In considering the genesis of concretions rich in iron and manganese carbonate, it may be assumed that either (1) the concretions grew on the bottoms of bodies of water by accessions of iron and manganese from salts in solution or (2) the concretions formed in the sediments after burial by the local reduction and migration of iron and manganese present as oxides in the sediments.

From the thermal relations of the oxides and carbonates of iron and manganese established many years ago by Dieulafait, it appears that less heat is absorbed by the reduction of manganic to manganous oxides than of ferric to ferrous oxides and more heat is evolved by the formation of manganous carbonate than of ferrous carbonate. The relations described above, when viewed in the light of these thermal data, indicate that the concretions have grown after burial by accessions of carbonates formed by reduction of the higher oxides of iron and manganeses present in sediments. (*Author's abstract.*)

Discussed by Messrs. BURCHARD, SPENCER, BRADLEY and HEWETT.

(*To be continued*)

## SCIENTIFIC NOTES AND NEWS

THE Smithsonian Institution announces that a perfect sphere of flawless crystal, believed to be the largest in the world, is now the property of the United States National Museum, thanks to the generosity of Mrs. Worcester Reed Warner. Mrs. Warner made the gift as a memorial to her late husband, whose own outstanding achievements were largely in the manufacture of astronomical instruments from quartz.

The crystal ball measures 12¾ inches in diameter and weighs 106¾ pounds. Perfect spheres of as much as 6 inches in diameter are great rarities, prized alike by emperors and museums, so that the uniqueness of the National Museums's acquisition may be realized.

The block of quartz from which the ball was cut is said to have come from Burma and must have weighed over 1,000 pounds. It was cut in China and polished in Japan. Eighteen months were required for this delicate and laborious task. According to Dr. George F. Kunz, the Japanese workmen first round the rough mass of crystal by careful chipping with a small steel hammer, forming a perfect sphere with the aid of this tool alone. For grinding they use cylindrical pieces of cast iron, about a foot in length and full of perforations, in which the ball is kept constantly turning. The abrasive material used in this first grinding is powdered emery and garnet. The final polishing is effected with crocus or rouge (finely divided hematite), giving a splendid lustrous surface.

The ball came to this country in 1925 and was immediately placed on temporary deposit in the National Museum. The officials of that institution express their pleasure that Mrs. Warner's gift makes it the permanent property of the nation. The late Mr. Warner, to whom the gift is a memorial, was a member of the firm of Warner and Swasey, instrument makers. Mr. Warner designed and constructed three of the largest telescopes in use in this hemisphere, including the 36-inch instrument of the Lick Observatory, the 40-inch telescope of the Yerkes Observatory and the 72-inch telescope for the Dominion of Canada.

DR. WARD B. WHITE, for the last eight years director of the bureau of chemistry, New York State Department of Agriculture and Markets, has accepted an appointment as chief of food control, Food, Drug, and Insecticide Administration, to fill the vacancy caused by the death of R. W. BALCOM.